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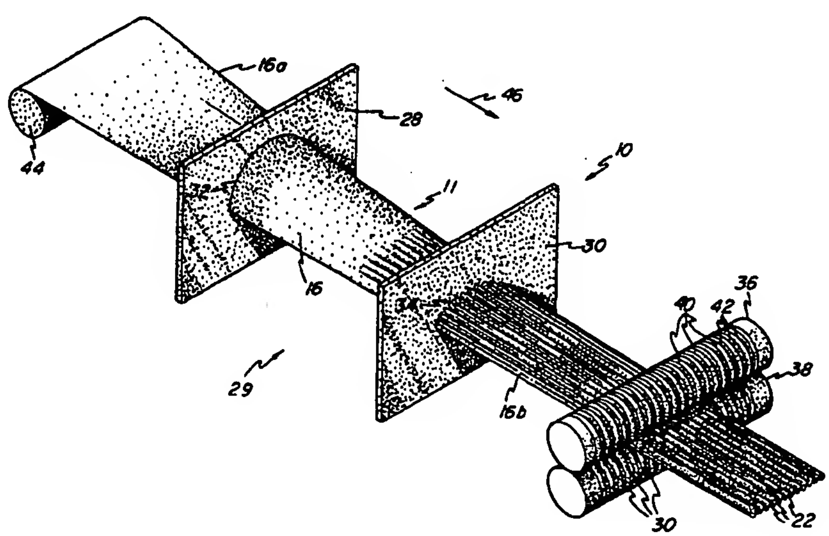

(57) Abstract

A method and apparatus for forming machine direction flutes within a continuous web is disclosed. The apparatus includes a first forming curve (34) in a first plane (30) including engagement points which deform the web (16). The first forming curve includes alternating ridges and grooves (22). A second forming curve (32) in a second plane (28) includes engagement points which deform the web. The second plane is disposed parallel to the first plane. Each of the engagement points of the second forming curve is associated with one of the engagement points of the first forming curve. The distance of the path of travel for each point is substantially equal to the distance of each path of travel for the adjacent point. The paths of travel converge in a direction from the second forming curve toward the first forming curve to define a three-dimensional forming surface (11) which forms the web into three dimensions.

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LENGTHWISE WEB CORRUGATOR

Background of the Invention

1. Field of the Invention

The present invention relates to a method and apparatus for forming flutes or pleats in a web and, more particularly, to a method and apparatus for forming flutes or pleats longitudinally, or in the machine-direction, in a moving web.

2. Description of the Prior Art

While the invention described herein could be used for any web material, it is particularly useful for the manufacture of corrugated paperboard.

Continuous sheets of paperboard are traditionally formed in the machine direction wherein the paper fibers tend to lie parallel to the direction of flow through the paper machine. In other words, the majority of paper fibers within a web of paperboard are aligned along the length of the web, i.e., in the machine direction. Paper is therefore non-isotropic, having significantly greater crush strength in the machine direction as opposed to the perpendicular cross-machine direction.

Conventional corrugated paperboard is manufactured with flutes extending in the weaker cross-machine direction. In other words, flutes are formed extending in the widthwise, or cross-machine, direction of the paperboard web. More particularly, the paperboard is fluted by passing the paperboard between a pair of corrugating rolls having intermeshing teeth oriented in the cross-machine direction, or perpendicular to the direction of travel of the web. The intermeshing teeth form flutes within the paperboard web wherein the flutes extend in the cross-machine direction. While the flutes add strength in the cross-machine direction, as noted above, the paper is inherently stronger in the machine direction. Therefore, the strength added by the flutes does not build upon the inherent strength of the paperboard. Thus, the maximum potential crush strength of the paperboard is not realized.

Traditionally, increased paperboard crush strength has been obtained by increasing the fiber content of the paperboard. The fiber content of the paperboard is increased by adding to the amount of pulp which is utilized in the

process of fabricating the paperboard. Thus, the consumption of raw materials is significantly increased as the need for stronger paperboard arises. It may be appreciated that if flutes could be formed in the machine direction, a corrugated box manufactured from the resultant paperboard web would have greater crush strength without requiring an increase in paperboard thickness. Alternatively, thinner paperboard could be used to create a corrugated box with the same crush strength as a corrugated box utilizing much heavier paperboard, thereby reducing the relative consumption of energy and raw materials.

Numerous methods and apparatuses for forming flutes in the machine direction of a continuous web have been proposed. While some of these methods and apparatuses have identified that various points along the width of the web will necessarily follow path lengths of different values as the flutes are formed, none have been successful in providing a machine direction corrugator which effectively equalizes these varying path lengths. Failure to adequately equalize the path lengths of different points across the width of the web will cause significant strain on the web, often resulting in the ripping or tearing of the web as it is conveyed through the corrugator. Such problems due to unequal path lengths increase dramatically with webs having substantial unfluted widths, since points located near the center of the web will traditionally have significantly different path lengths than points located near the opposing side edges of the web.

Accordingly, there is a need for a method and apparatus for forming machine direction flutes within a web and which provides a forming surface which substantially equalizes the travel of all points across the width of the web as it travels through the apparatus.

Summary of the Invention

The present invention comprises a method and apparatus for fluting a web in the machine direction. The apparatus includes a first, or exit, forming curve disposed within a first, or exit, plane and including a plurality of engagement points adapted to contact and deform the web as the web travels in a direction downstream through the first plane. The first forming curve includes an arc length extending between opposing side edges of the web. A second, or entrance, forming curve is

disposed within a second, or entrance, plane and includes a plurality of engagement points adapted to contact and deform the web as it travels in a direction downstream through the second plane. The second plane is disposed substantially parallel to and upstream in spaced relation from the first plane. The second forming curve includes an arc length extending between the opposing side edges of the web wherein the arc length of the first forming curve is substantially equal to the arc length of the second forming curve. The engagement points of the second forming curve are associated with corresponding engagement points of the first forming curve thereby defining an associated pair of engagement points. The engagement points defining any one associated pair are positioned at substantially the same arc length distance from a center of each respective first and second forming curves.

Each associated pair of engagement points defines a path of travel of a surface point of the web between the first and second forming curves wherein the surface point is positioned at a location in the cross-machine direction of the web. The length of each path of travel is substantially equal to the length of each adjacent path of travel. The paths of travel converge in a direction from the second forming curve towards the first forming curve.

A three dimensional forming surface includes entrance and exit ends defined by the first and second forming curves. Cross-sections taken along the forming surface and parallel to the first and second forming curves result in intermediate forming curves, each forming curve having an arc length substantially equal to the cross-machine width of the unfluted web. Each of the intermediate forming curves intersects the paths of travel formed between the first and second forming curves. Engagement points of the forming curves constrain the upper and lower surfaces of the web to conform to the forming surface as the web travels downstream from the second forming curve to the first forming curve.

The second forming curve is a function of the unfluted width of the web, a maximum height of the second forming curve and a take-up factor. The take-up factor is a function of the unfluted width of the web and the fluted width of the web. In the preferred embodiment, a plurality of elongated forming members extend along at least some of the paths of travel and provide at least some of the engagement points adapted to contact the web. A pair of cooperating rolls including intermeshing

circumferentially disposed alternating ridges and grooves are positioned downstream from the second plane and are driven in motion thereby pulling the web through the apparatus.

The method of the present invention includes the steps of providing a continuous web of material having an initial unfluted width and providing a forming device including entrance and exit ends defining entrance and exit forming curves. The web is conveyed through the forming device from the entrance end toward the exit end thereby causing the web to conform to the entrance forming curve at the entrance end and causing the web to conform to the exit forming curve at the exit end. Each point along the width of the web is constrained to travel along a path of travel between the entrance and the exit forming curves wherein a length of the path of travel for each point along the width of the web is substantially equal to a length of any other path of travel. The plurality of paths of travel combine to define a three dimensional forming surface.

Therefore, it is an object of the present invention to provide a method and apparatus for fluting a web of material.

It is a further object of the present invention to provide such a method and apparatus for forming flutes in the direction of travel of the web.

It is another object of the present invention to provide a method and apparatus for producing a corrugated paperboard which is stronger, per weight, than conventional corrugated paperboard.

It is still yet another object of the present invention to provide a method and apparatus for achieving substantially equal travel of all points across the width of the web as the web passes through the apparatus.

It is a further object of the present invention to provide a method and apparatus for constraining a moving web to follow a three dimensional surface such that all points across the width of the web follow the same path length as flutes are formed within the web.

It is another object of the present invention to provide a method and apparatus which may be used to flute, in the machine direction, corrugated paperboard having a substantial width, e.g., at least forty inches.

Other objects and advantages of the invention will be apparent from

the following description, the accompanying drawings and the appended claims.

Brief Description of the Drawings

Fig. 1 is a perspective view, in partial schematic, illustrating the properties of first and second forming curves of the preferred embodiment of the invention;

Fig. 2 is a schematic view of the properties of the entrance forming curve of the invention;

Fig. 3 is a perspective view, in partial schematic, illustrating the properties of an intermediate forming curve of the invention;

Fig. 4 is a schematic view of successive cross-sections taken along the right half of the forming surface of Fig. 1 and progressing from the entrance plane to the exit plane;

Fig. 5 is a side elevational view of the web as constrained by the forming surface of the invention;

Fig. 6 is a top plan view of Fig. 5;

Fig. 7 is a perspective view of a first embodiment of the apparatus of the invention;

Fig. 8 is a perspective view of a second embodiment of the apparatus of the invention;

Fig. 9 is a cross-sectional view taken along 9-9 of Fig. 8;

Fig. 10 is a perspective view of a third embodiment of the apparatus of the invention; and

Fig. 11 is a cross-sectional view taken along line 11-11 of Fig. 10.

Detailed Description of the Preferred Embodiment

Term Definitions

The following provides a list of terms and their associated definitions as used in the remainder of the description of the present invention.

$\bar{S}_n$ The path of travel of a point on the web traveling through the corrugator.

s Length of vector $\bar{s}_n$.

L Distance between parallel first and second forming planes.

$\bar{q}_n$ The endpoint of vector $\bar{s}_n$ on the second forming plane.

$\bar{p}_n$ The endpoint of vector $\bar{s}_n$ on the first forming plane.

$\bar{p}_n'$ The projection of point $\bar{p}_n$ onto the second forming plane.

w The cross-machine width of the unfluted web.

dw The distance between adjacent points $\bar{q}_n$ and $\bar{q}_{n+1}$ on the second forming plane.

f The cross-machine width of the fluted web.

df The distance between adjacent points $\bar{p}_n$ and $\bar{p}_{n+1}$ on the first forming plane, defined as (dw/t).

t The take-up factor, defined as (w/f) which is equivalent to (dw/df).

C The second forming curve in the second forming plane defined by the locus of points $\bar{q}_n$.

h The maximum height of the second forming curve C.

d The distance from $\bar{q}_n$ to $\bar{p}_{n+1}'$ on the second forming plane.

m Number of flutes across the fluted web.

P The line segment in the first forming plane defined by the locus of points $\bar{p}_n$.

F The first forming curve in the first forming plane corresponding to the fluted cross-section of the web.

D_n An intermediate forming curve in an intermediate forming plane disposed between the first and second forming planes.

$\bar{r}_n$ The point formed by the intersection of a path of travel $\bar{s}_n$ and

an intermediate forming curve D_n.

δ The arc length between adjacent points $\bar{q}_n$, $\bar{p}_n$ and $\bar{q}_{n+1}$, $\bar{p}_{n+1}$ on each of the forming curves F, D and C.

ϕ Converging angle of the opposing side edges of the web at the second forming plane, defined as arctan (h/L).

Mathematical Derivation of the Forming Surface

Referring initially to Fig. 1, the corrugator 10 of the present invention includes a three dimensional forming surface 11 which extends between substantially parallel first, or exit, and second, or entrance, forming planes 12 and 14. The forming surface 11 is adapted to contact a paperboard web 16 as the web 16 is pulled through the corrugator 10 wherein the web 16 includes an unfluted portion 16a upstream of the second forming plane 14 and a fluted portion 16b downstream of the first forming plane 12. The first and second planes 12 and 14 are proximate exit and entrance ends of the corrugator 10 and are spaced apart from each other by a distance L.

In the first plane 12, the surface 11 forms a first, or exit, forming curve F which is fluted and includes a plurality of alternating forming ridges, or forming flutes 18, and forming grooves 20 corresponding to a cross-section of a fluted portion 16a of the web 16. In other words, each forming flute 18 of the curve F is associated with at least one web flute 22 of the fluted portion 16b of the web 16. The first forming curve F includes an arc length extending between opposing side edges 24 and 26 of the web 16 wherein the arc length of the forming curve F is substantially equivalent to the arc length of the fluted web 16b.

The first forming curve F intersects a line P at a plurality of exit points $\bar{p}_n$ which preferably comprise a first plurality of exit engagement points positioned on the tips of the forming flutes 18 adapted to contact and deform the web 16 as the web 16 travels in a longitudinal direction through the corrugator 10. In the second plane 14, the surface 11 forms a second, or entrance, forming curve C which is unfluted. The arc length of the second forming curve C extends between side edges 24 and 26 of the web 16 and is substantially equal to the width w of the

unfluted web portion 16a.

The second forming curve C is defined by a locus of entrance points $\bar{q}_n$ which preferably comprise a plurality of entrance engagement points for contacting and deforming the web 16 as it enters the corrugator 10. The entrance points $\bar{q}_n$ are preferably equally spaced a distance dw apart along the arc length w of the curve C. In order to reduce the resultant strain in the web 16 as the web 16 is fluted, the arc lengths of the first and second forming curves F and C are defined as being substantially equal. In other words, the arc lengths of the forming curves F and C are substantially equal to the width w of the unfluted web 16a, such that strain on the web 16 as it follows the contour of the forming curves F and C is substantially reduced if not eliminated.

For every point $\bar{q}_n$ on the second forming curve C, there is an associated point $\bar{p}_n$ in the first forming plane 12 thereby defining an associated pair of points $\bar{q}_n$, $\bar{p}_n$. Each point $\bar{p}_n$ in the first forming plane 12 is preferably spaced a distance df from each adjacent point $\bar{p}_{n+1}$, and all points $\bar{p}_n$ preferably line in a straight line P extending across the width of the web 16 between opposing side edges 24 and 26. If the distance between adjacent exit points $\bar{p}_n$ and $\bar{p}_{n+1}$ df is selected as the distance between flutes 16, then each point $\bar{p}_n$ will lie on the tip of a forming flute 18. Each associated pair of points $\bar{p}_n$, $\bar{q}_n$ defines a path of travel, represented by vector $\bar{s}_n$ in Fig. 1. The path of travel $\bar{s}_n$ extends from $\bar{p}_n$ to $\bar{q}_n$ and has a length s. The length s is defined as the equal path length constraint, wherein:

(1) $\bar{q}_n - \bar{p}_n \equiv \bar{s}_n$; and

(2) $|s_n| \equiv s$ for all n.

By arbitrarily selecting the location of one point $\bar{q}_0$ on second forming curve C, the remainder of the points $\bar{q}_n$ can be determined from the equal path length constraint s. If it is assumed that the second forming curve C is convex, symmetrically disposed about the y axis, and has a maximum height of h, then the location of the entrance point $\bar{q}_0$ which is the apex of the second forming curve C, is defined as:

(3) $$\bar{q}_0 = (0, h, 0)$$

The location of $\bar{p}_0$ as follows:

(4) $$\bar{p}_0 = (0, 0, L)$$

All of the exit points $\bar{p}_n$ in the first forming plane 12 are defined to lie along line P of height 0 above the x axis. The value of the path length s and the locations of projected point $\bar{p}_0'$, exit point $\bar{p}_1$, and projected point $\bar{p}_1'$ may therefore be calculated as follows:

(5) $$s = \left|\bar{p}_0 - \bar{q}_0\right| = \sqrt{L^2 + h^2}$$

(6) $$\bar{p}_0' = \bar{p}_0 - (0, 0, L) = (0, 0, 0)$$

(7) $$\bar{p}_1 = \bar{p}_0 + (df, 0, 0) = (df, 0, L)$$

(8) $$\bar{p}_1' = \bar{p}_1 - (0, 0, L) = (df, 0, 0)$$

The task now is to locate the entrance point $\bar{q}_1$. First, the distance from entrance point $\bar{q}_1$ to projected point $\bar{p}_1'$ must be determined. The distance from exit point $\bar{p}_1$ to projected point $\bar{p}_1'$ is by definition the distance L between the

first and second planes 12 and 14. Since the distance between the associated pair of points $\bar{q}_1$, $\bar{p}_1$ is the length s of the path of travel $\bar{s}_n$, and the vector $\left(\bar{q}_1 - \bar{p}_1'\right)$ is perpendicular to the vector $\left(\bar{p}_1' - \bar{p}_1\right)$, the distance from $\bar{q}_1$ to $\bar{p}_1'$ must be the height h of the second forming curve C. It is also known by definition that the distance from point $\bar{q}_0$ to adjacent point $\bar{q}_1$ is dw. Finally, calculating the distance from point $\bar{q}_0$ to projected point $\bar{p}_1'$ on the second plane:

(9) $$\left|\bar{q}_0 - \bar{p}_1'\right| = \left|(0, h, 0) - (df, 0, 0)\right| = \sqrt{df^2 + h^2} \equiv d$$

Turning now to Fig. 2, three sides of a triangle are known and trigonometry may be utilized to find the angle from the x axis to entrance point $\bar{q}_1$. The angle α may be found from the formula:

(10) $\alpha = 2 \arctan (B/ (A-dw))$; where

(11) $A = \frac{1}{2} (d + dw + h)$; and

(12) $$B = \sqrt{\frac{(A-d)(A-dw)(A-h)}{A}}$$

The angle β may then be found as follows:

(13) $$\beta = \pi - \arctan\left(\bar{q}_0^{\,y} / (\bar{p}_1'^{\,x} - \bar{q}_0^{\,x})\right),$$

where the x and y superscripts in equation (13) indicate the x and y components of their respective vectors. Finally,

(14) $\theta = \beta - \alpha$

(15) $$\bar{q}_1 = \bar{p}_1' + (h \cos(\theta), h \sin(\theta), 0)$$

The same formulas as described in detail above may be used to find adjacent point $\bar{q}_2$ from point $\bar{q}_1$, and so on, for all engagement points $\bar{q}_n$ wherein

n=0 to (w/2dw). In other words, each point $\bar{q}_n$ may be found by reference to an adjacent point $\bar{q}_{n-1}$. This will generate points $\bar{q}_n$ for half the second forming curve C, which is symmetric about the y axis. It should be noted that accuracy of the second forming curve C is improved if the distance dw between adjacent points $\bar{q}_n$ is very small. The value of dw should preferably be no larger than (m/w) where, as stated above, m is the number of flutes 16 across the first forming curve F, and w is the cross-machine width of the unfluted web 20.

Further note that the shape of the second forming curve C is dependent on the values of the unfluted web width w, the distance dw between adjacent points $\bar{q}_n$ on the second forming curve C, the take-up factor t (which defines df), and height of the second forming curve h, but is not dependent on the distance L between the first and second planes 12 and 14. The take-up factor t is defined as the ratio of the width w of the unfluted web portion 16a over the width f of the fluted web portion 16b. The take-up factor t is also equal to the ratio of the distance dw between adjacent points $\bar{q}_n$ on the second forming curve C and the distance df between adjacent points $\bar{p}_n$ on the first forming curve F as defined by the equation:

(16) $t = (w/f) = (dw/df)$

Note that h is the only arbitrarily-selected parameter in determining the shape of the second forming curve C. If the selected value for h is too small, the resultant curve C will loop in on itself and h must be increased. However, there is no maximum value for the height h of second forming curve C.

Referring now to Figs. 1 and 3, the three dimensional flute forming surface 11 extending between the first and second forming curves F and C is preferably constructed in the following manner. The first forming curve F with the fluted cross-section is superimposed onto the line P defined by the locus of exit points $\bar{p}_n$. Line P preferably intersects the first forming curve F at the flute tips $\bar{p}_n$. As noted above, the arc length of the first forming curve F must be substantially

equal to the width w of the unfluted web portion 16a in order to avoid unacceptable strain on the web 16.

As illustrated in Fig. 3, one or more intermediate forming planes 27 are aligned parallel to and intermediate the first and second forming planes 12 and 14. An intermediate forming curve D_n is defined by initially selecting one of the intermediate forming planes 27. The paths of travel $\bar{s}_n$ are then identified as provided above. Next, points $\bar{r}_n$, which are the intersections of the paths $\bar{s}_n$ and the intermediate plane 27, are determined. The intermediate forming curve D_n is defined as a fluted curve having a frequency such that the points $\bar{r}_n$ intersect the curve D_n at regular intervals, preferably at the flute tips, and having an amplitude such that the arc length δ of each flute 18' is substantially equal to (w/m), wherein w equals the width w of the unfluted web 16a and m equals the number of flutes 22 across the width f of the fluted web 16b. In other words, the overall length of intermediate forming curve D_n is substantially equal to that of first forming curve F and second forming curve C.

The forming surface 11 is defined by the locus of first and second forming curves F and C in combination with intermediate forming curves D_n spaced at appropriate intervals. It may be appreciated that with the greater the number of intermediate forming curves D_n selected between first and second forming curves F and C, then the accuracy of the forming surface 11 increases. In other words, equalization of the path lengths s and arc lengths of the forming curves improve with the greater the number of forming curves D_n selected.

Fig. 4 shows an x-y plane view of cross-sections through the right half of the forming surface progressing from the second plane 14 to the first plane 12 of Fig. 1. As illustrated, the successive cross-sections comprise a plurality of parallel intermediate forming planes 27, each plane 27 including a two dimensional forming curve D_n gradually progressing from the shape of the second forming curve C to the shape of the first forming curve F. The successive forming curves D_n include progressively increasing depths of alternating grooves 18 interspaced between alternating flutes 16. While only two intermediate forming curves D_1 and D_2 are illustrated in Fig. 3, this in no way limits the scope of the invention and any number

of intermediate forming curves D_n may be positioned intermediate the first and second forming curves F and C.

As detailed above, it is essential that the arc length of each successive forming curve C, D_n and F be substantially equal in order to reduce the strain on the web 20. Further, once flutes 16 are defined on a forming curve D_n, then the number m of total flutes 16 must remain consistent on each successive downstream forming curve D_n and F. While the drawing figures illustrate a substantially sinusoidal shaped curve F, it may be appreciated that other shapes of the curve F may be utilized with the method and apparatus of the present invention, including substantially square or trapezoidal shaped curves.

Referring now to Figs. 5 and 6, the values selected for h and L will define the plane of travel of the web 16, since once the web flutes 22 are formed thereby increasing the rigidity or stiffness of the fluted web portion 16b, the exiting fluted web portion 16b should travel in as straight a path as possible to avoid permanent damage to or creasing of the web 16 due to sharp bending motions. The web flutes 22 are converging as they approach the first plane 12 from the second plane 14, as shown in the x-z plane view in Fig. 5.

After passing plane 12 the flutes 22 become parallel, and they must turn an angle ϕ, causing some strain on the web. L and h should be selected to minimize ϕ as required for the material being fluted. If the value of h is such that the outermost edges of the second forming curve C have a height of zero, as in Fig. 5, then the maximum converging angle ϕ, at the outside edges of the web 20, will be equal to the arctangent of the ratio of the height h of the second forming curve C and the distance L between the first and second planes 12 and 14:

(17) $\phi = \arctan(h/L)$

Note that if L is zero, the flute forming will occur entirely in the second plane 14, and the fluted web 20 will continue traveling in the -y direction. In such a case, ϕ can be reduced by making h very large.

As may be appreciated from the above derivation of the forming surface 11, it is critical for the proper formation of longitudinal or machine direction flutes 22 that strain on the web 16 be minimized. The present invention provides a three dimensional forming surface 11 which effectively eliminates this strain by

requiring that the points across the width of the web 16 travel a substantially equal distance from the second forming curve F to the first forming curve C. The forming surface 11 is also constructed to require that the first and second forming curves C and F, as well as any intermediate forming curves D, to have substantially equivalent arc lengths extending between the opposing side edges 24 and 26 of the web 16. In other words, the forming surface 11 accounts for the gradually deepening forming flutes 18 and grooves 20 as the paperboard web 16 travels from the second curve C to the first curve F while simultaneously accounting for the reduction in width of the web 16 from an unfluted width w to a fluted width f.

It should be noted that the exit and entrance points $\bar{p}_n$ and $\bar{q}_n$ need not comprise the exit and entrance engagement points of the first and second curves F and C. As detailed hereinbelow, the exit and entrance engagement points are positioned on the first and second curves F and C, respectively, and therefore possess the same properties as the exit and entrance points $\bar{p}_n$ and $\bar{q}_n$.

It should be further noted that the path length constraint s is ideally equal for all path of travel vectors s_n. However, given that paper typically tears at approximately 5% strain, the values of s for each vector $\bar{s}_n$ may vary by up to approximately 5% without significantly damaging the paper web. Further, the arc lengths of each adjacent forming curve C, D_n and F may likewise vary by approximately 5%. It should be noted that the possible variance of path length s and arc length of forming curves C, D_n and F may vary depending upon the resilient properties of the particular web 16 being fluted.

<u>Mechanical embodiment of the forming surface.</u>

The corrugator 10 of the present invention may constrain the web 16 to follow the shape of the forming surface 11 by any one of a wide variety of means. Points lying along the first, second and intermediate forming curves F, C and D_n are selected as engagement points for engaging and conforming the web 16 to the approximate shape of the respective curves F, C and D_n. These engagement points may comprise points $\bar{p}_n$, $\bar{q}_n$ and $\bar{r}_n$ or any other combination of points lying along

respective forming curves F, C and D_n as defined by points $\bar{p}_n$, $\bar{q}_n$ and $\bar{r}_n$.

In a first embodiment as illustrated in Fig. 7, a die assembly 29 includes entrance and exit dies 28 and 30 which are disposed in parallel relationship with each other. Each die 28 and 30 includes a slot 32 and 40 for receiving and deforming the web 16. A conveyor preferably comprising a pair of cooperating rolls 36 and 38 and supporting a conveyor die is disposed downstream from the dies 28 and 30. The conveyor die preferably comprises intermeshing alternating ridges 40 and grooves 42 formed within the outer surface of the rolls 36 and 38. The cooperating rolls 36 and 38 are driven in motion thereby pulling the web 16 through the dies 28 and 30 as supplied from a source of material 44.

The slot of the entrance die 28 is preferably in the shape of the second forming curve C. The plurality of intermeshing ridges 40 and grooves 42 on the cooperating pulling rolls 36 and 38 are substantially identical to the forming ridges 18 and grooves 20 of the first forming curve F. The slot 34 in the second die 30 is in the shape of an intermediate curve D_n. As the web 16 is pulled in the direction of arrow 46, the web flutes 22 gradually deepen as the two dimensional curves D_n of the forming surface 11 flattens. The flutes 22 in the web 16 reach their full depth at the forming surface F which is preferably defined by the pulling rolls 36 and 38.

While a pair of dies 28 and 30 are illustrated in Fig. 7, it may be appreciated that at least one intermediate die could be positioned between the dies 28 and 30 wherein the intermediate die includes a slot in the shape of a second intermediate curve D_n. A plurality of such intermediate dies could be combined to form a continuous die assembly for forming the web 16.

Figs. 8 and 9 illustrate a second embodiment of the corrugator 10 of the present invention, wherein the die assembly 29 includes a plurality of wheel assemblies 48 which are disposed successively in a downstream direction as indicated by arrow 46. Each wheel assembly 48 is spaced from each adjacent wheel assembly 48. Once again, a pair of circumferentially fluted driven pulling rolls 36 and 38 disposed downstream of the wheel assemblies 48. As described above, the circumferentially fluted rolls 36 and 38 intermesh to define the shape of the first forming curve F. The wheel assembly 48a disposed in a furthest upstream position

defines a shape of the second forming curve C. The wheel assemblies 48b and 48c are arranged intermediate the wheel assembly 48a and the cooperating rolls 36 and 38 and define intermediate curves D_1, and D_2.

As illustrated in Fig. 9, each wheel assembly 48 includes an upper cross support member 50 and a lower cross support member 52, each supporting a plurality of arms 54. A wheel 56 is rotatably supported on each arm 54 and arranged so as to define an engagement point of respective forming curves C, D_n, F. As the web 16 is pulled through the successive wheel assemblies 48, the flutes 22 are formed longitudinally, or in the machine direction, within the web 16 as detailed above.

Turning now to Figs. 10 and 11, a third embodiment of the die assembly 29 of the corrugator 10 of the present invention is illustrated as including a plurality of die bars or rods 58 extending between entrance and exit die supports 60 and 62. Each die support 60 and 62 includes an upper die block 64 and a lower die block 66, the die blocks 64 and 66 supporting upper and lower sets 68 and 70 of the rods 58 arranged in a manner to define the forming surface 11. The pair of circumferentially fluted pulling rolls 36 and 38 are disposed downstream from the die supports 60 and 62 and cooperate to define the shape of the first forming curve F as described above. The rods 58 proximate the entrance die support 60 cooperate to define the second forming curve C. As illustrated in Fig. 11, the upper and lower sets 68 and 70 of rods 58 intermediate the die supports 60 and 62 define intermediate forming curves D_n gradually changing shape from the second forming curve C to the first forming curve F as the rods 58 progress from the first die support 60 to the rolls 58.

The rods 58 may be arced or bowed intermediate the dies supports 60 and 62 as needed to ensure that each engagement point along the length of the rods 58 intersects an appropriate point along each successive intermediate forming curve D_n. The method of calculating the points $\bar{r}_n$ in order to ensure that the arc length of each intermediate forming curve D_n is substantially equal and that the length s of each path of travel vector $\bar{s}_n$ is substantially equal is described above in greater detail.

In the above described embodiments of the corrugator 10 of the present invention, the forming surface 11 initially constrains the web 16 to form flutes or undulations in the web 16 corresponding to an intermediate forming curve D_n. The web 16 is then transported downstream through the rolls 36 and 38 where the web 16 is formed into the final fluted portion 16b corresponding to the shape of forming curve F. However, the forming surface 11 may form flutes or undulations in the web 16 corresponding to the forming curve F wherein the rolls 36 and 38 are positioned downstream of curve F. Further, as noted above, the shape of the alternating ridges 40 and grooves 42 on the rolls 36 and 38 may be of a different shape than that of a cross-section of the forming surface 11. For example, the die assembly 29 may comprise substantially sinusoidal forming curves D_n, while the cooperating rolls 36 and 38 may comprise a square or trapezoidal forming curve F as long as the arc length of the curve defined by the rolls 36 and 38 is substantially the same as the upstream forming curves C and D_n.

Many web materials, such as paper, will form more easily with the application of heat and moisture. The corrugator 10 of the present invention may therefore include means for heating and moistening the web. For example, the dies or wheels may be heated, or an external source of heat may radiate through the dies or wheels. Referring again to Fig. 10, the die rods 58 may include internal chambers 72 communicating with a fluid source (not shown). Apertures 74 may be provided in fluid communication with the chambers 72 for releasing air, steam, or other similar fluids to create a hydrodynamic or fluid bearing 76 intermediate the surface of the die rods 58 and the web 16. Such a fluid bearing 76 substantially reduces the force required to pull the web 16 through the die rods 58, as well as providing heat and moisture to facilitate flute formation. It is also envisioned that the wheels of Fig. 7 may be driven in motion to reduce the frictional forces acting against the web 16.

The method and apparatus of the present invention provides a forming surface which substantially equalizes the paths of travel of each point along the width of a moving web 16 while simultaneously ensuring a constant arc length of each successive forming curve. As such, the method and apparatus of the present invention may be utilized with webs of virtually any width for the formation of flutes having any of a wide variety of cross-sectional shapes.

While the method herein described, and the forms of apparatus for carrying this method into effect, constitute preferred embodiments of this invention, it is to be understood that the invention is not limited to these precise methods and forms of apparatus, and that changes may be made in either without departing from the scope of the invention, which is defined in the appended claims.

--CLAIMS--

1. An apparatus for fluting a web having opposing side edges, an initial unfluted cross-machine width extending between said side edges, and a final fluted cross-machine width extending between said side edges, said apparatus comprising:

a first forming curve disposed within a first plane and including a first plurality of engagement points adapted to contact and deform said web as said web travels in a longitudinal direction downstream through said first plane, said first forming curve including an arc length extending between said opposing side edges of said web;

a second forming curve disposed within a second plane and including a second plurality of engagement points adapted to contact and deform said web as said web travels in said longitudinal direction downstream through said second plane, said second plane being disposed substantially parallel to and upstream in said longitudinal direction from said first plane, said second forming curve including an arc length extending between said opposing side edges of said web, said arc length of said first forming curve being substantially equal to said arc length of said second forming curve;

said engagement points of said second forming curve being associated with corresponding ones of said engagement points of said first forming curve thereby defining associated pairs of engagement points; and

wherein said associated pairs of engagement points define paths of travel of surface points of said web between said first and second forming curves, at locations between said opposite side edges of said web, the length of each said path of travel being substantially equal to the length of each adjacent said path of travel.

2. The apparatus of claim 1 wherein each said associated pair of engagement points contacts a substantially identical said surface point across said width of said web as said web travels downstream from said second forming curve to said first forming curve.

3. The apparatus of claim 1 wherein said paths of travel converge in a direction from said second forming curve towards said first forming curve.

4. The apparatus of claim 3 wherein said paths of travel combine to form said web into three dimensions between said second plane and said first plane.

5. The apparatus of claim 4 wherein said paths of travel define a three-dimensional forming surface extending between said first and second planes.

6. The apparatus of claim 1 wherein:

each said path of travel has a length within approximately 5 percent of a length of each adjacent said path of travel; and

said arc length of said second forming curve is within approximately 5 percent of said arc length of said first forming curve.

7. The apparatus of claim 1 further comprising a plurality of elongated forming members extending along at least some of said paths of travel and providing said engagement points of at least one of said first and second forming curves.

8. The apparatus of claim 1 further comprising at least first and second dies providing said engagement points of at least one of said first and second forming curves, each of said dies including a slot for receiving the web.

9. The apparatus of claim 1 further comprising at least first and second arrays of rotatably mounted wheels providing said engagement points of at least one of said first and second forming curves.

10. The apparatus of claim 1 further comprising a pair of cooperating rolls including intermeshing circumferentially disposed alternating ridges and grooves, said rolls positioned downstream from said second plane.

11. The apparatus of claim 10 wherein said pair of cooperating rolls define said first forming curve.

12. The apparatus of claim 1 wherein said second forming curve is a function of said unfluted width of said web, a maximum height of said second forming curve and a take-up factor, said take-up factor being a function of said unfluted width of the web and said fluted width of said web.

13. An apparatus for fluting a web of material including opposing side edges, an initial cross-machine unfluted width between said side edges, and a final cross-machine fluted width between said side edges, said apparatus comprising:

an entrance end adapted for receiving said web;

an exit end positioned downstream along a longitudinal axis from said entrance end and adapted for receiving said web;

a three-dimensional forming surface defined between said entrance end and said exit end and adapted for forming flutes in said web as said web is conveyed from said entrance end to said exit end in contact with said forming surface;

an exit forming curve defined by a cross-section of said forming surface proximate said exit end and including a plurality of ridges and grooves formed by a locus of exit points, said exit forming curve extending within two dimensions in an exit forming plane;

an entrance forming curve defined by a cross-section of said forming surface proximate said entrance end and formed by a locus of entrance points, said entrance forming curve extending within two dimensions in an entrance plane disposed substantially parallel to and in spaced relation from said exit plane, said entrance points associated with corresponding ones of said exit points thereby defining a plurality of associated pairs of points; and

wherein said associated pairs of points define paths of travel of surface points of said web between said entrance forming curve and said exit forming curve, the length of each path of travel being substantially equal to the length of each adjacent said path of travel and greater than a distance along said longitudinal axis between said entrance plane and said exit plane.

14. The apparatus of claim 13 wherein said entrance curve is a function of said unfluted width of said web, a maximum height of said entrance forming curve and a take-up factor, said take-up factor being a function of said unfluted width of said web and said fluted width of said web.

15. The apparatus of claim 13 wherein:

successive parallel cross-sections of said forming surface taken progressively from said entrance plane to said exit plane comprise a plurality of two dimensional intermediate forming curves gradually progressing from the shape of said entrance curve to the shape of said exit curve, each said intermediate forming curve defined by a locus of points disposed on said paths of travel connecting said associated pairs of points; and

each said forming curve has an arc length extending between said opposing side edges of said web, said arc length of each said forming curve being substantially equal to said arc length of each adjacent said forming curve.

16. The apparatus of claim 13 wherein each said path of travel has a length within approximately 5 percent of a length of each adjacent said path of travel.

17. The apparatus of claim 13 further comprising a pair of cooperating rolls including intermeshing circumferentially disposed alternating ridges and grooves, said rolls positioned downstream of said entrance plane.

18. An apparatus for forming a fluted web of material having opposing side edges and a width between said side edges, said apparatus comprising:

a plurality of flute forming curves successively arranged in a longitudinal direction, each said forming curve extending in two dimensions within a forming plane and having an arc length between said opposing side edges of said web;

each of said forming planes disposed substantially parallel and in spaced relation to each adjacent said forming plane;

said arc length of each said forming curve substantially equal to said

arc length of each adjacent said forming curve;

a plurality of points defining each said curve, said points of one said curve associated with corresponding ones of said points of every other said curve to define a plurality of sets of associated points; and

wherein each said set of associated points are interconnected to define a path of travel of a surface point of said web, each said path of travel having a length substantially equal to a length of every other said path of travel.

19. The apparatus of claim 18 wherein a first one of said forming curves includes a plurality of alternating grooves and ridges corresponding to a cross-section of a fluted web.

20. The apparatus of claim 19 wherein said successive ones of said forming curves taken in a direction toward said first one of said forming curves include progressively increasing depths of alternating grooves interspaced between alternating ridges.

21. The apparatus of claim 18 wherein each said path of travel has a length within approximately 5 percent of a length of each adjacent said path of travel.

22. An apparatus for forming a fluted web, said apparatus comprising:

a forming device including a plurality of engagement points adapted for contacting a web traveling between first and second planes, said plurality of points positioned along first and second forming curves extending in two dimensions within said first and second planes;

a first forming curve disposed within said first plane and including a plurality of said engagement points adapted to contact said web traveling through said first plane, said first forming curve including a plurality of alternating ridges and grooves corresponding to a cross-section of a fluted web;

a second forming curve disposed within said second plane and including a plurality of said engagement points adapted to contact said web, said second plane disposed substantially parallel to and upstream from said first plane,

said engagement points of said second curve being associated with corresponding ones of said engagement points of said first curve thereby defining associated pairs of engagement points;

wherein said associated pairs of engagement points define paths of travel of surface points of said web between said first and second forming curves, said surface points positioned at spaced locations in the cross-machine direction of said web, the length of each said path of travel being substantially equal to the length of each adjacent said path of travel; and

a conveyor disposed downstream of said forming device for pulling said web through said first and second planes.

23. The apparatus of claim 22 further comprising a die supported on said conveyor for completing flute formation in said fluted web.

24. The apparatus of claim 23 wherein said conveyor comprises a pair of cooperating rolls including intermeshing circumferentially disposed alternating ridges and grooves.

25. The apparatus of claim 22 further comprising a heater in thermal communication with said forming device for transferring heat to said web.

26. The apparatus of claim 22 further comprising at least one fluid chamber in fluid communication with said forming device for providing a fluid bearing between at least one of said engagement points and said web.

27. The apparatus of claim 26 wherein said fluid comprises steam.

28. The apparatus of claim 22 further comprising a plurality of elongated forming members extending along at least some of said paths of travel and providing said engagement points of at least one of said first and second forming curves.

29. The apparatus of claim 22 further comprising at least first and second dies providing said engagement points of at least one of said forming curves, each of said dies including a slot for receiving the web.

30. The apparatus of claim 22 further comprising at least first and second arrays of rotatably mounted wheels providing said engagement points of at least one of said forming curves.

31. A method of forming a fluted web, said method comprising the steps of:

providing a continuous web of material having opposing side edges and an initial unfluted width between said side edges;

providing a forming device including entrance and exit ends defining entrance and exit forming curves, said entrance and exit forming curves extending within entrance and exit forming planes and having entrance and exit arc lengths between said opposing side edges of said web, said entrance plane disposed substantially parallel to said exit plane;

conveying said web through said forming device from said entrance end toward said exit end;

causing a plurality of entrance engagement points positioned along said entrance forming curve to conform said web to a shape of said entrance forming curve at said entrance end;

causing a plurality of exit engagement points positioned along said exit forming curve to conform said web to a shape of said exit forming curve at said exit end thereby forming a fluted web having a final fluted width; and

constraining each point along the width of said web to travel along a path between said entrance and exit forming curves, a length of said path for each said point being substantially equal to a length of each adjacent said path, wherein said plurality of paths combine to define a three dimensional forming surface.

32. The method of claim 31 wherein said entrance forming curve is a function of said unfluted width of said web, a maximum height of said entrance

forming curve and a take-up factor, said take-up factor being a function of said initial unfluted width of said unfluted web and said final fluted width of said fluted web.

33. The method of claim 31 further comprising the step of providing a fluid film between said forming device and said web.

34. The method of claim 31 further comprising the step of supporting at least some of said engagement points on rotatable members.

35. The method of claim 31 further comprising the step of equalizing each said path length to within 5 percent of each adjacent said path length.

36. The method of claim 31 wherein said arc length of said entrance forming curve is substantially equal to said arc length of said exit forming curve.

37. The method of claim 31 wherein said forming curves are connected by a plurality of elongated forming members extending between at least some of said associated pairs of engagement points and in substantially parallel relation to said paths of travel.

FIG - 1

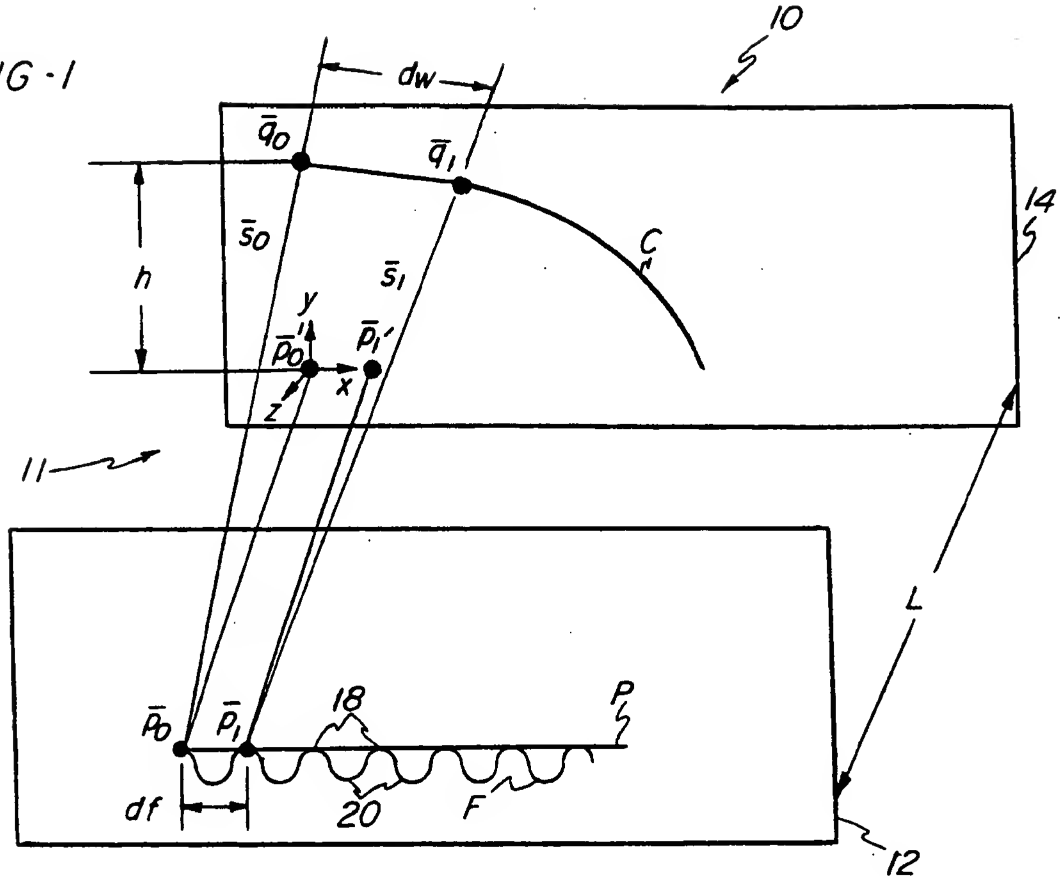
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FIG - 2

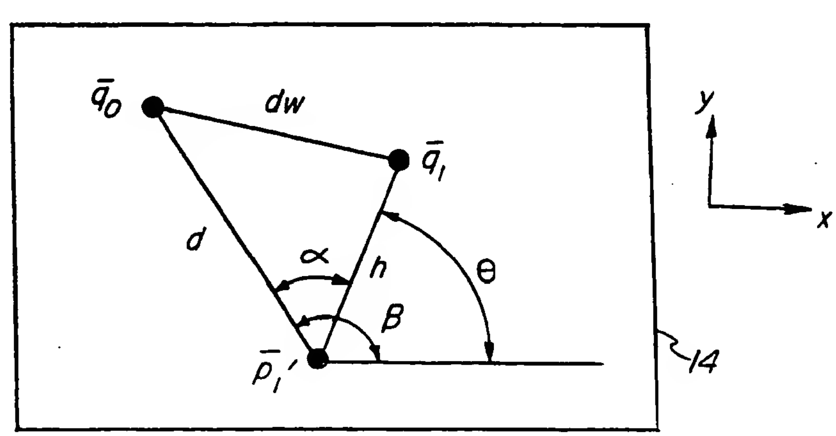
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FIG - 3

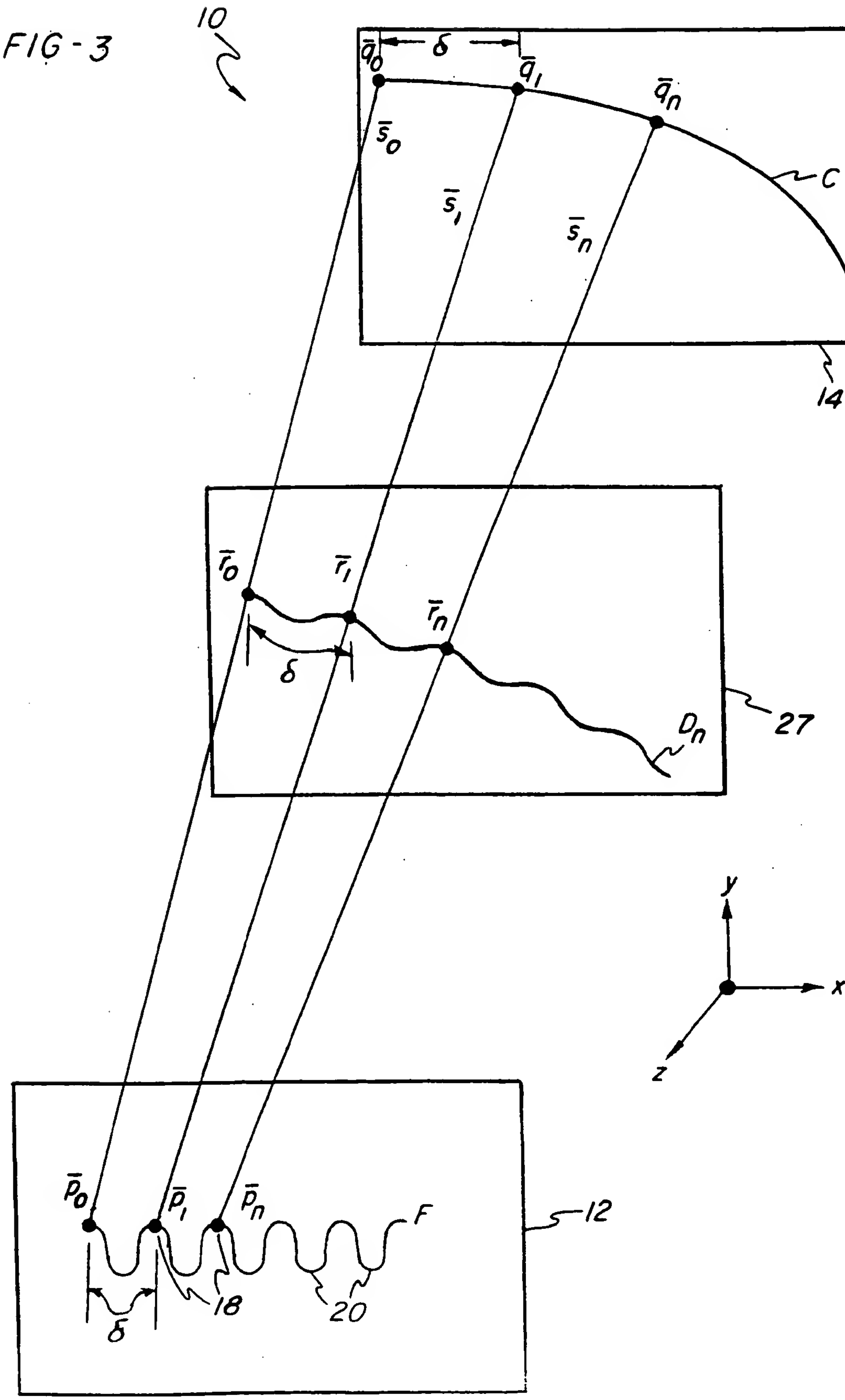
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FIG-4

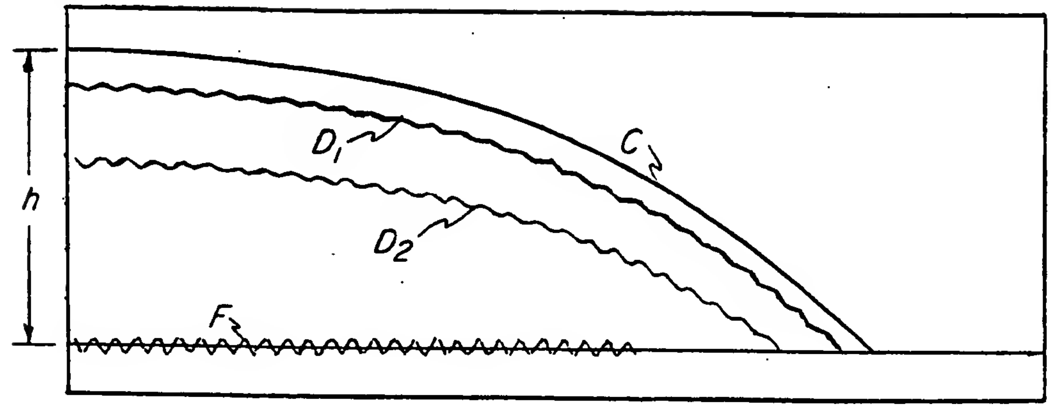


FIG-5

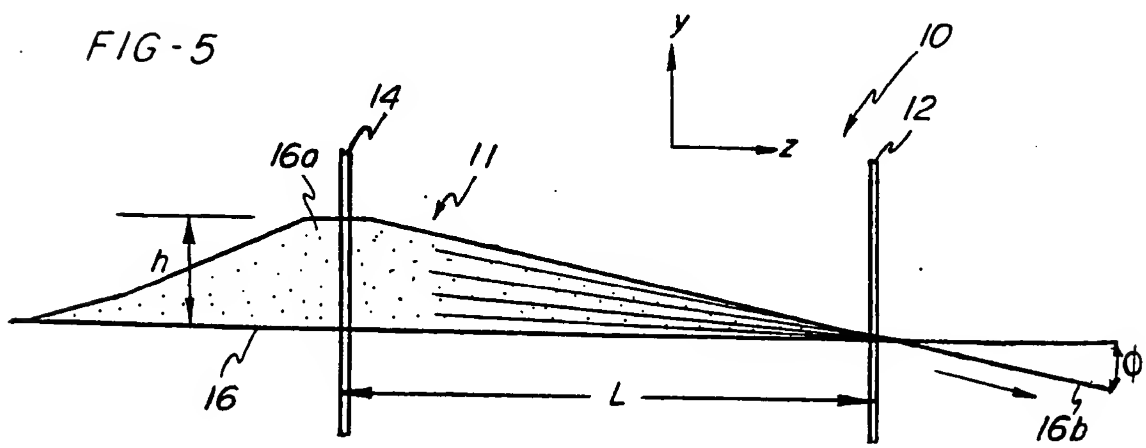
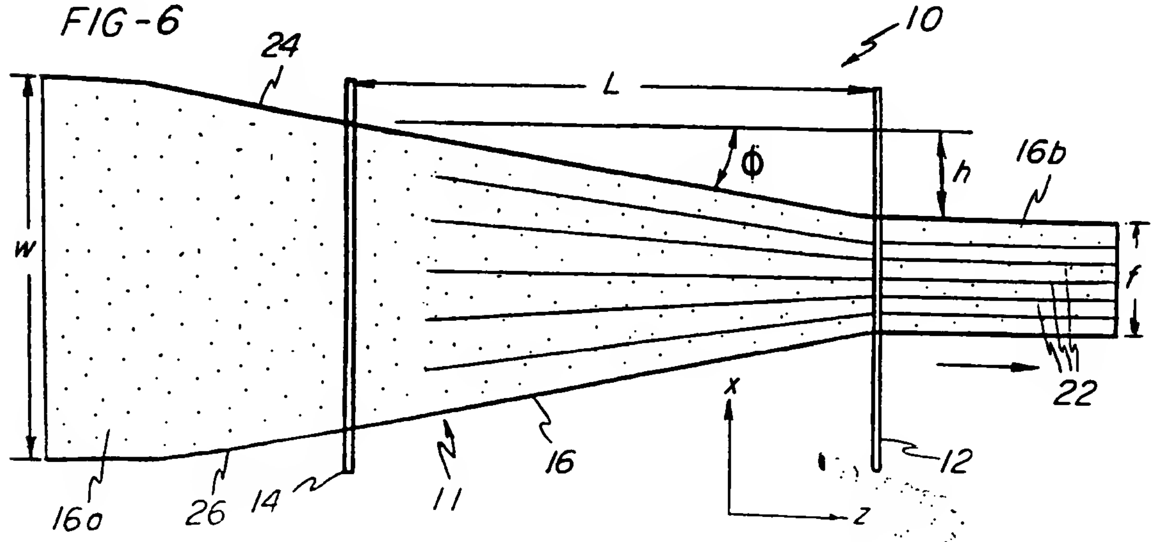


FIG-6



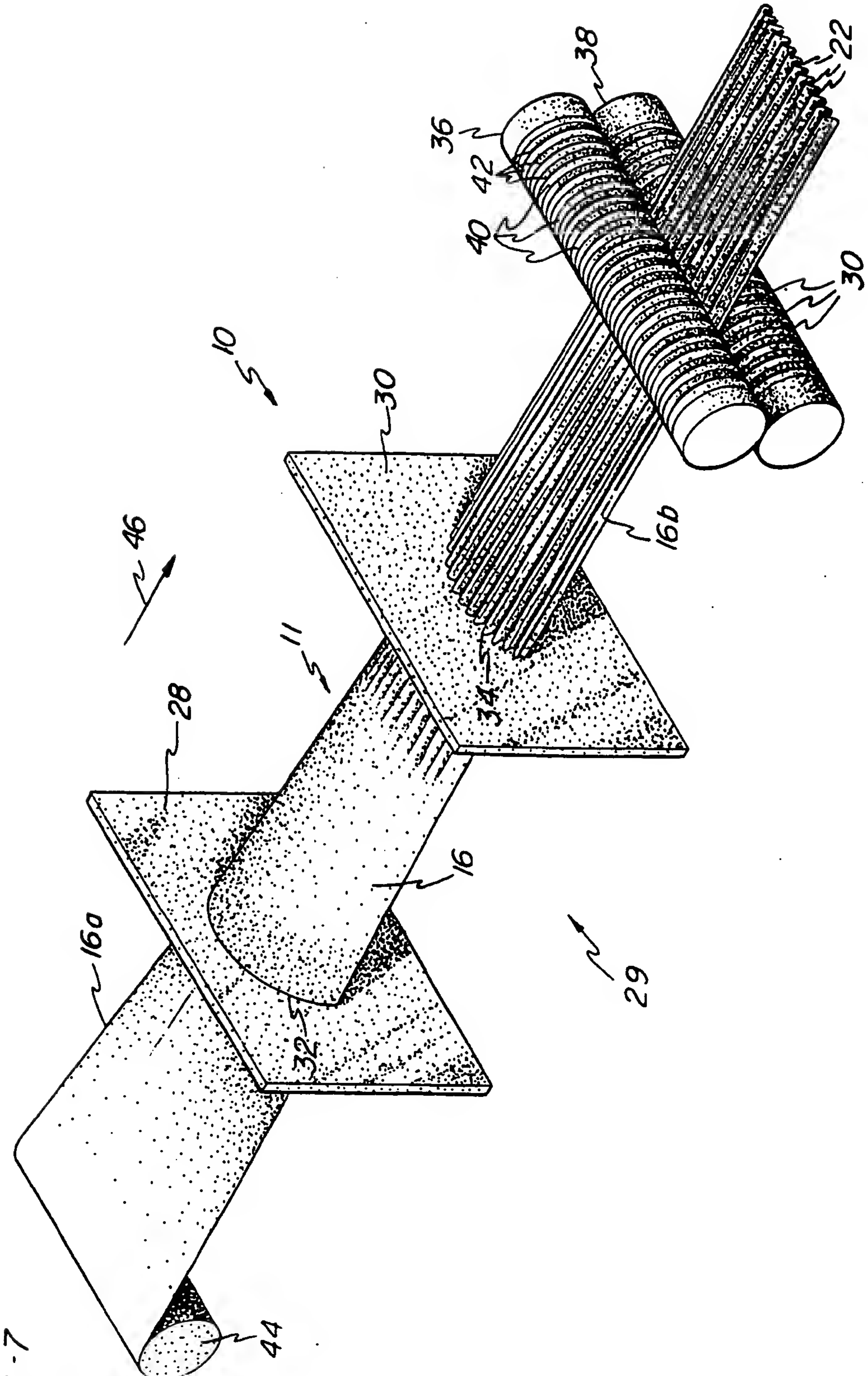


FIG-7

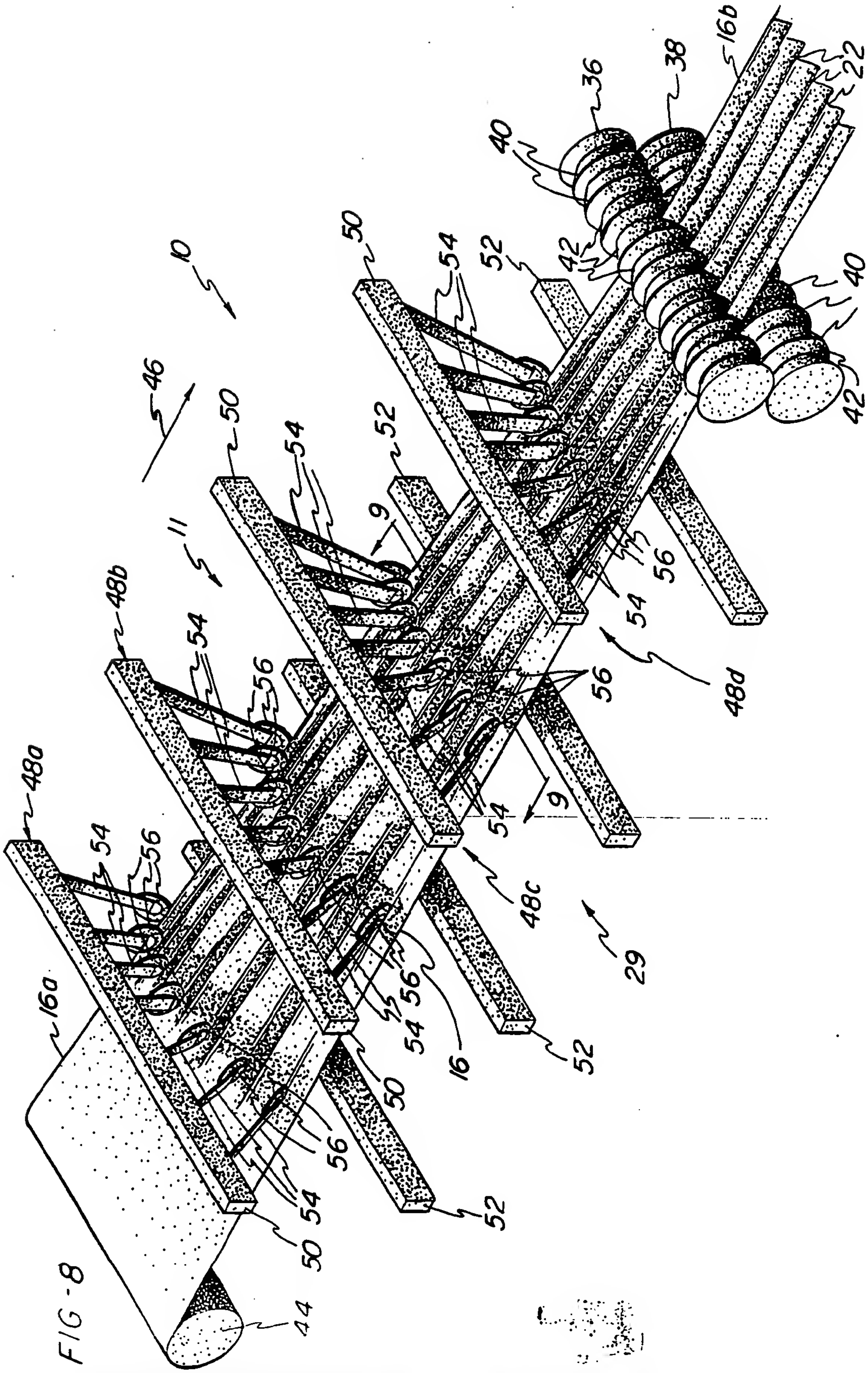


FIG-8

FIG - 9

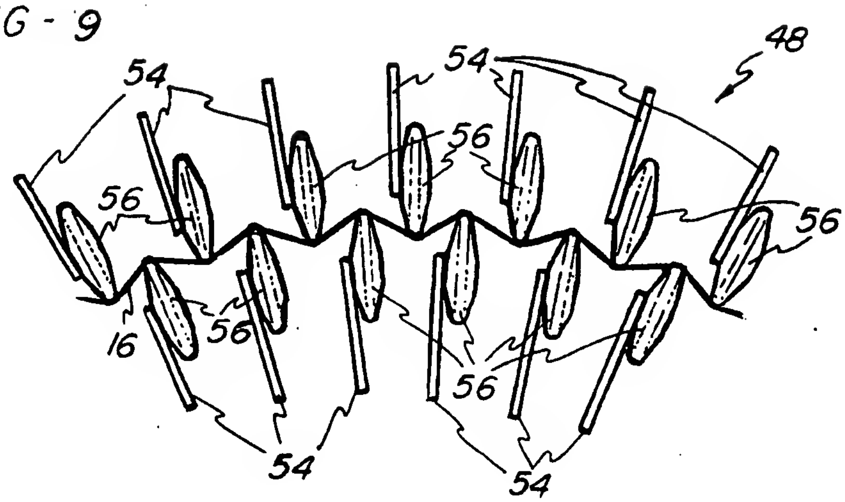

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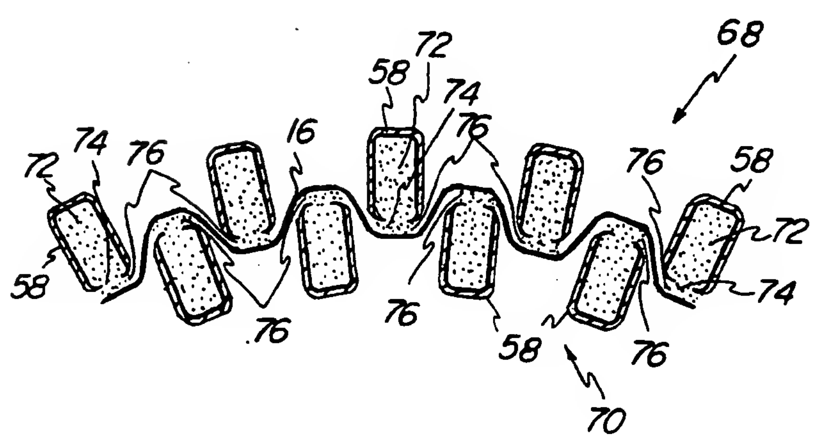
FIG - 11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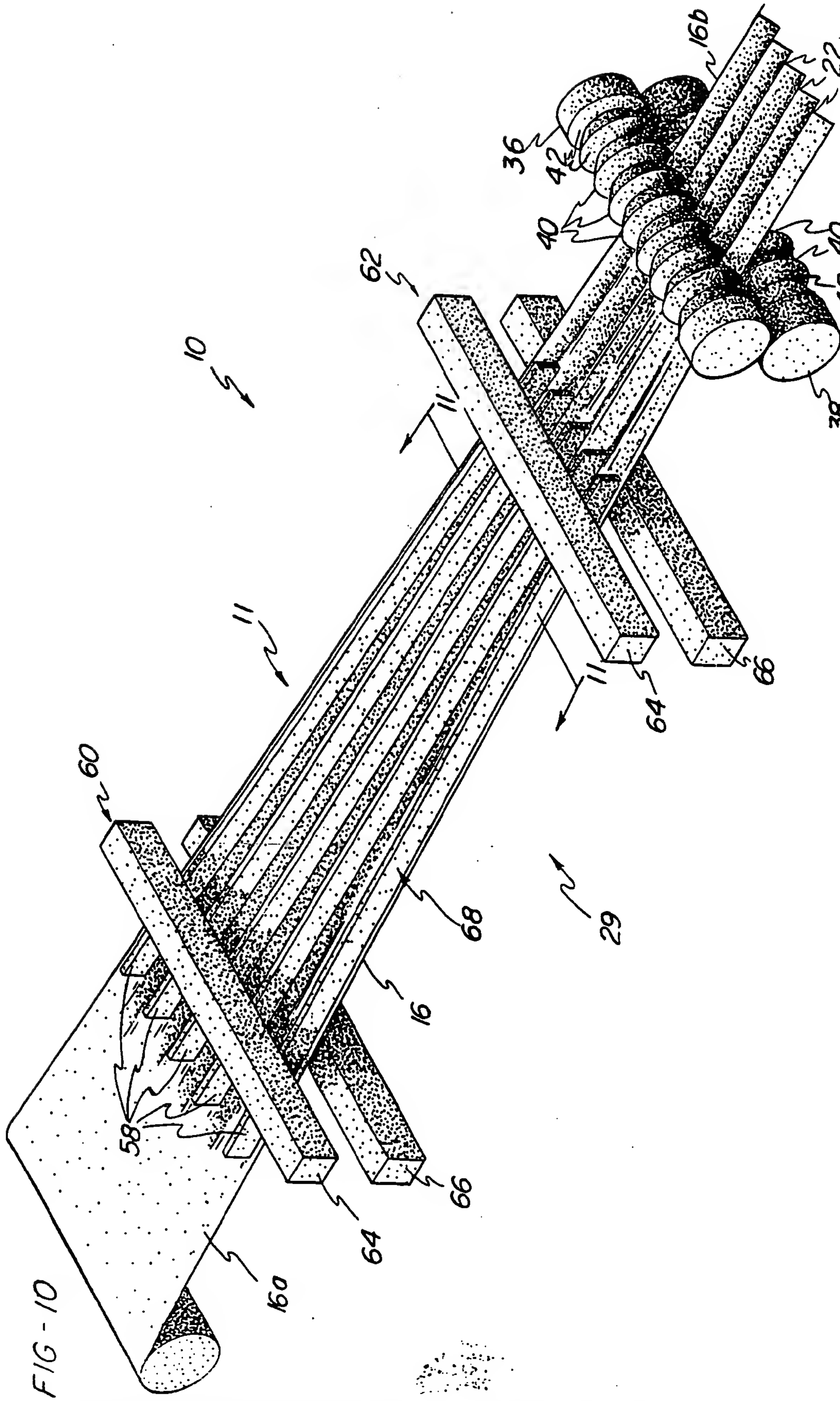

FIG - 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/05031

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :B31F 1/20
US CL :493/463; 264/286

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed hy classification symbols)

U.S. : 493/463, 435, 434, 440, 439, 436, 418, 450, 966, 941; 264/286

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

None

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

None

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 3,161,557 A (MULLER) 15 December 1964, col. 2, line 49 - col. 5, line 26, Fig. 1: reference numerals6, 8, 4, 10, 12, 9a, 9b and Fig. 4	1-25, 28, 29, 31, 32, 34-37
X X	US 4,223,059 A (SCHWARZ) 16 September 1980, col. 2, lines 42-50 and 61-65, Figs. 4 & 5: reference numerals 26, 28 and 35	1-24, 28, 29, 31, 32, 34-37
X	US 2,960,145 A (RUEGENBERG) 15 November 1960, Figs. 1 -5 and 13, reference numerals 15, 19, 12, 13, col. 5, line 16 - col. 7, line 56	1-24, 28, 29, 31, 32, 34-37
X Y	US 4,140,564 A (SCHRADER) 20 February 1979, col. 4, line 52 - col. 5, line 7	25, 26, 27, 33

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

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"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
17 MAY 1999	01 JUN 1999

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	PETER VO Sheila Veney Paralegal Specialist Technology Center 3700
Facsimile No. (703) 305-3230	Telephone No. (703) 305-044

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US99/05031

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,376,726 A (ROUYER ET AL) 09 April 1968, See Fig. 10	1-37
A	US 5,185,082 A (CHAPPELL et al) 09 February 1993, See Figs. 4 & 5	1-37

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